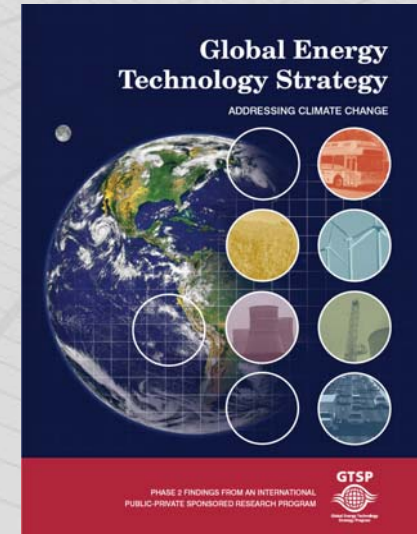


MODELING THE ENERGY-CLIMATE TRANSITION



THE LONG HAUL: NAVIGATING THE ENERGY TRANSITION TO LIMIT CLIMATE CHANGE

Dunsmuir Lodge (Victoria BC)

Jae Edmonds

August 12, 2008



Pacific Northwest
NATIONAL LABORATORY

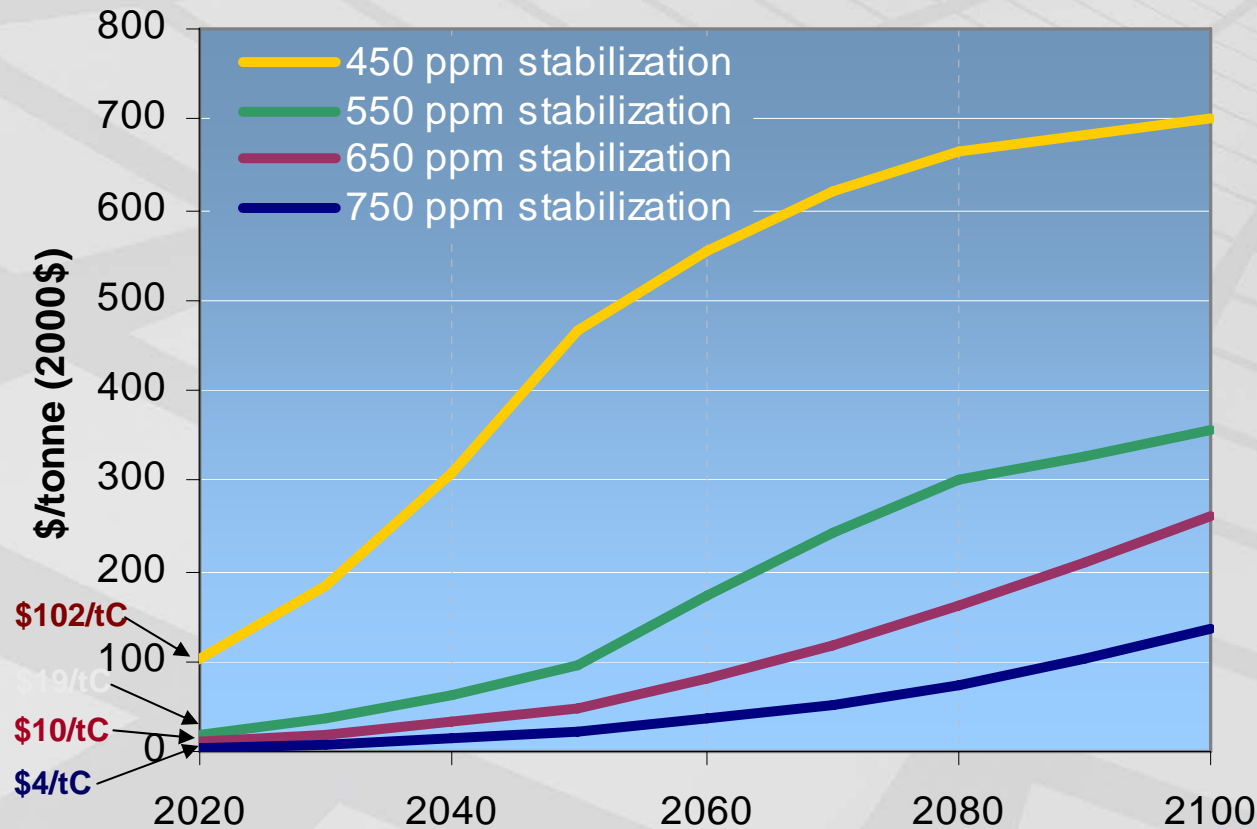
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Stabilization implies that greenhouse gases have a price—either implicitly or explicitly.

- ▶ If carbon and other GHG's are valued at zero, both implicitly and explicitly—you get the reference scenario.
- ▶ None of the reference scenarios that we have examined stabilize GHG concentrations at low levels.

The price of carbon should rise over time.

Global Value of Carbon

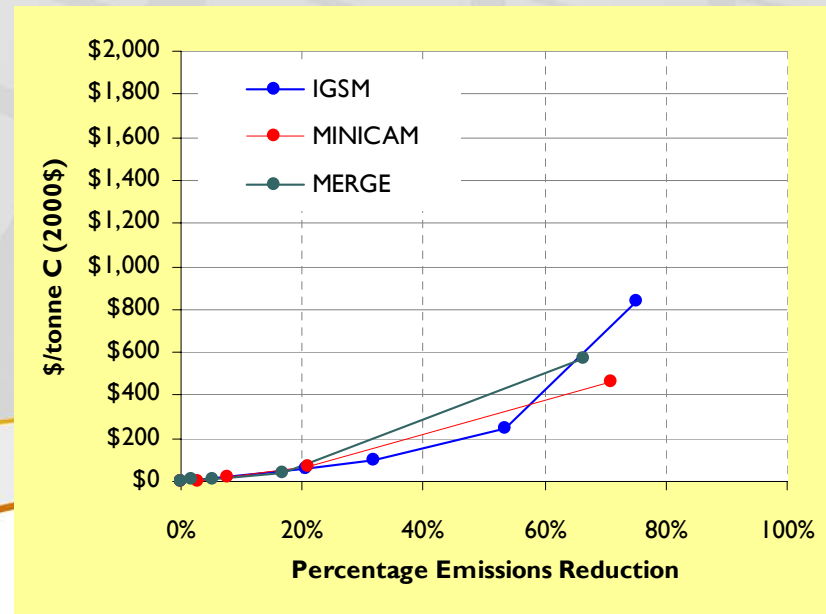
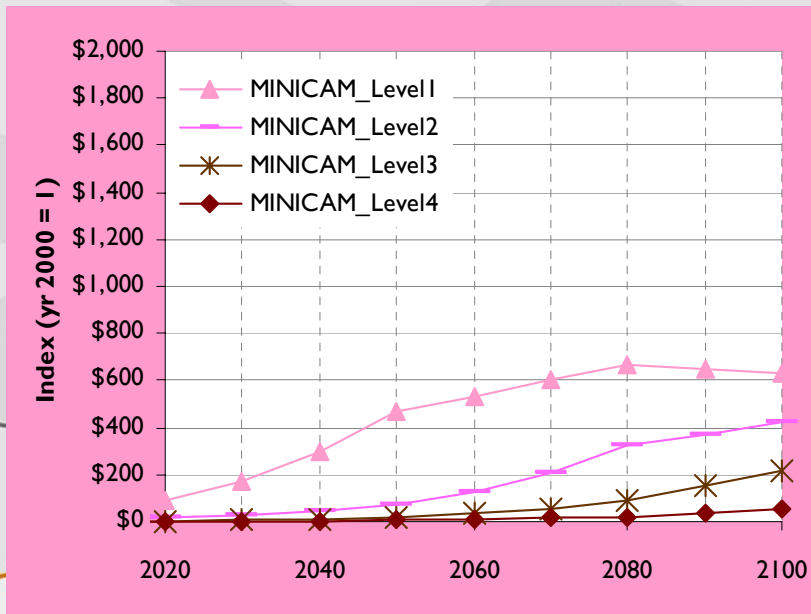
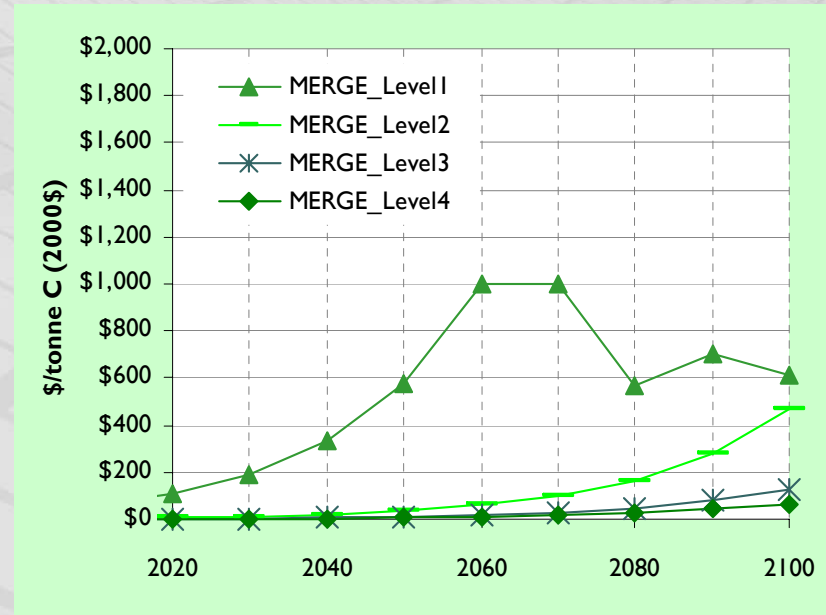
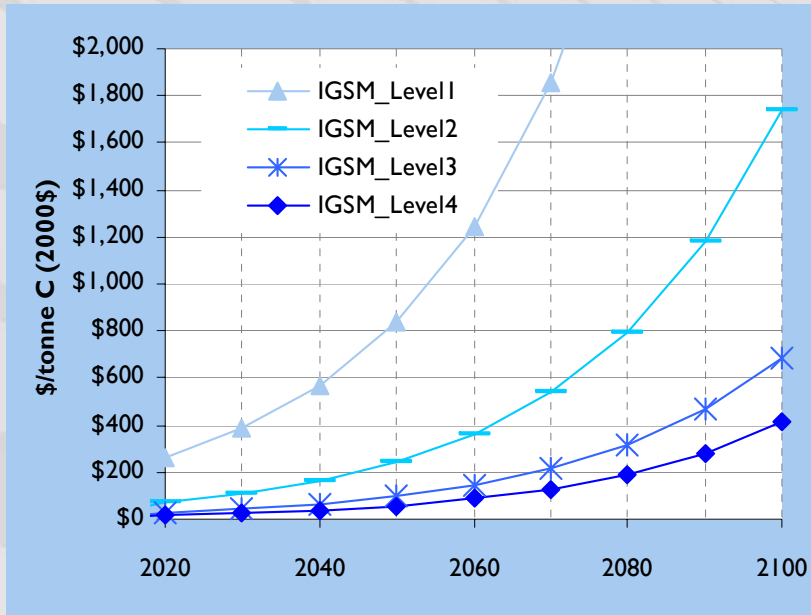


- ▶ **Climate change is a STOCK POLLUTANT problem, NOT a flow pollutant.**
- ▶ Price of carbon starts low and rises over time.
- ▶ Stabilization means tripping increasingly costly technology options as emissions are driven toward zero.

Decision makers should be able to form a reasonable expectation that the price will rise—NOT fall—over time.

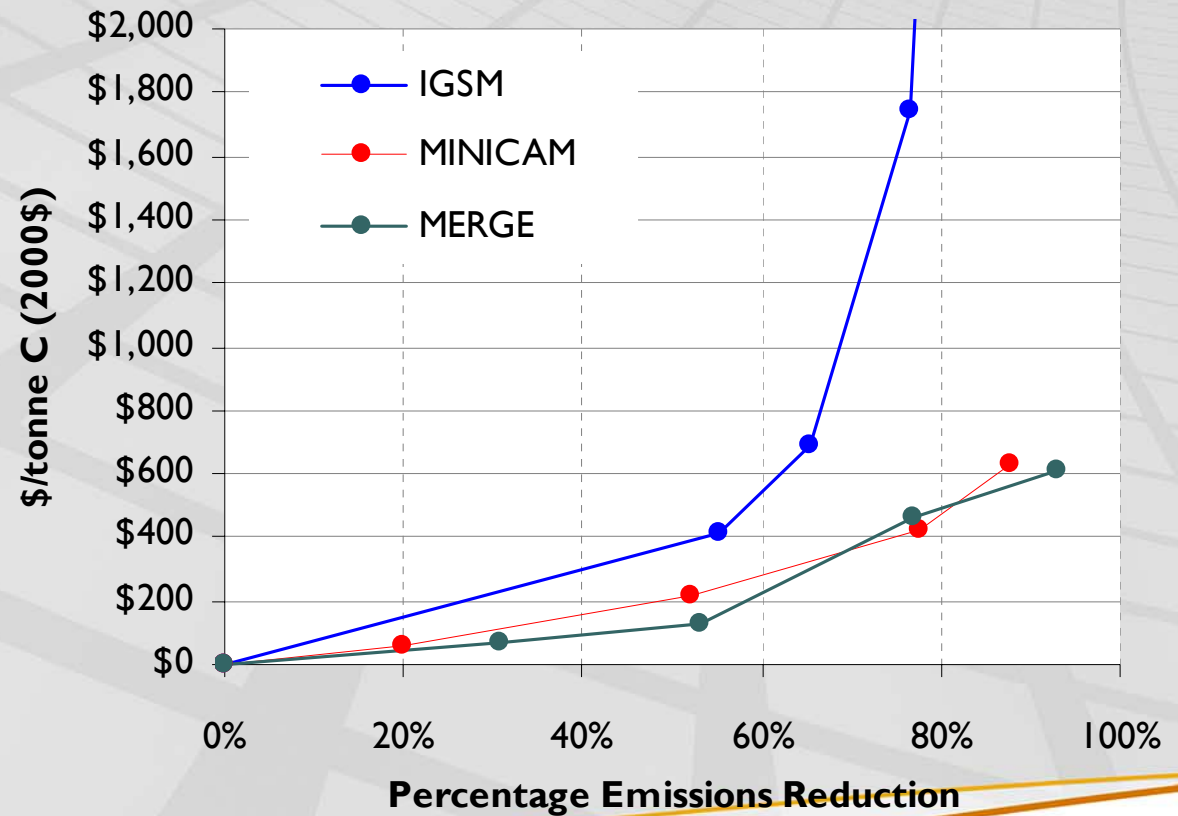
- ▶ The time when low-emission technologies enter into operation is dramatically accelerated when one of the cost elements (carbon emissions) is growing rapidly.
 - E.g. CCS will come into use long before the price of carbon reaches the point at which it would be sufficient to deploy the technology if it were held constant.
- ▶ The time horizon of emissions mitigation measures
 - Policies that are in effect for short periods of time and then expire make the creation of expectations difficult.
 - Even if policies extend indefinitely into the future, they will need regular review and re-pegging of the price to reflect learning.

Technology in the long term casts a shadow back to the present

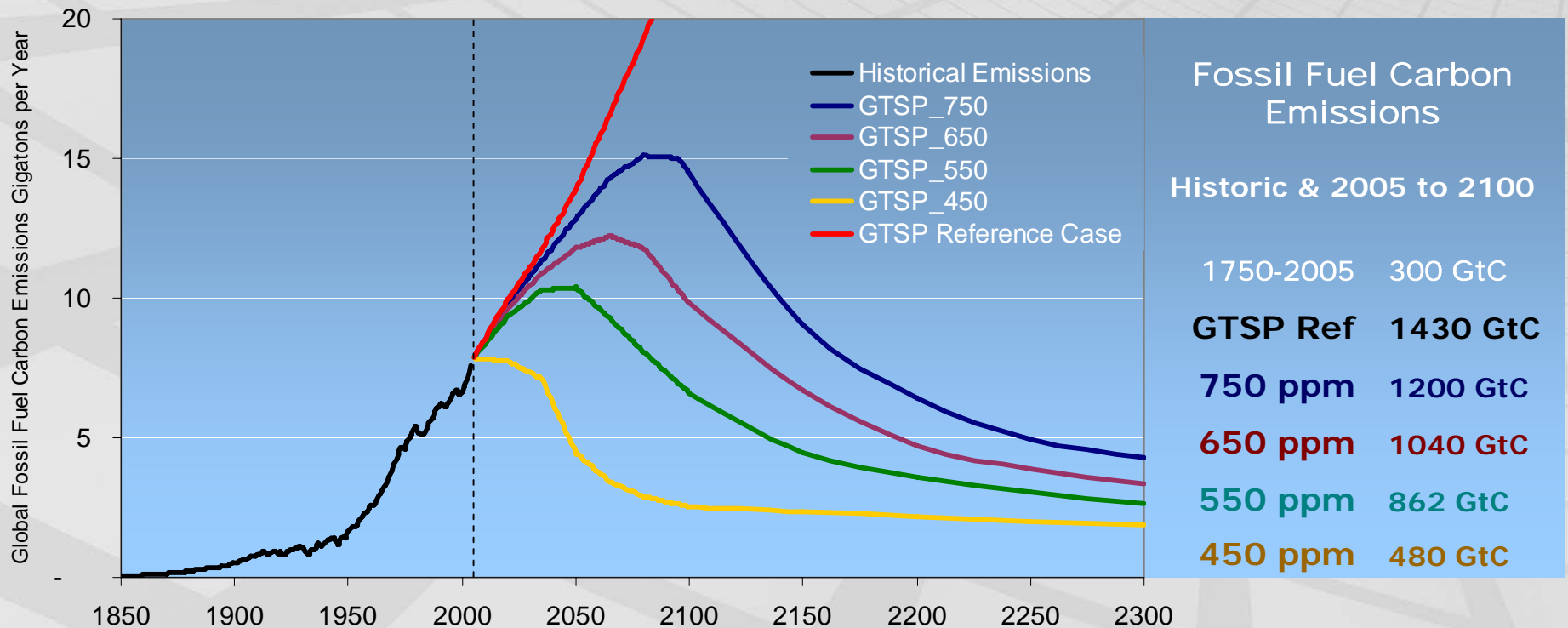


Technology assumptions in the post-2050 period are very different

- ▶ Because prices followed a modified “Hotelling” path, technology differences in the post-2050 period were reflected back to the present.



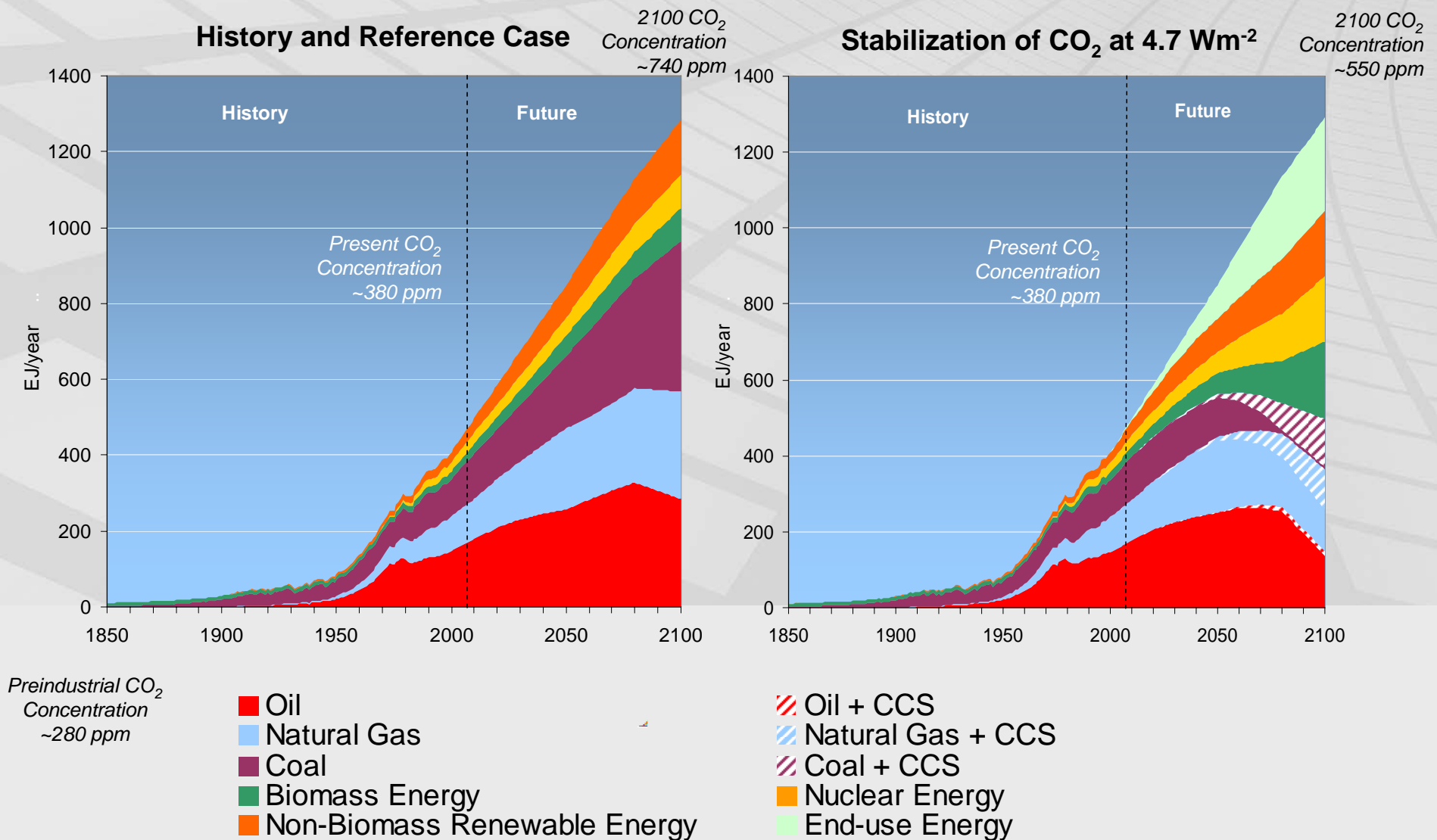
Stabilization of greenhouse gas concentrations means fundamental change to the global energy and land use systems.



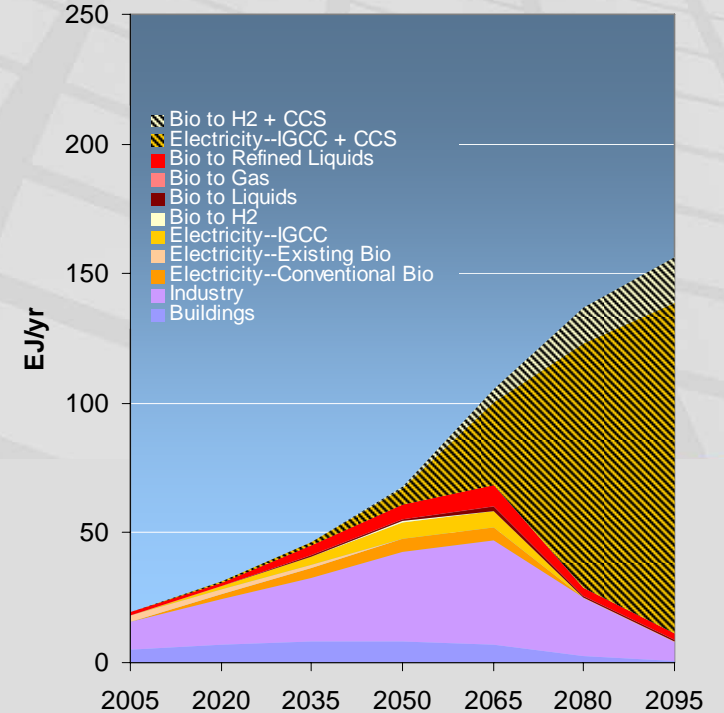
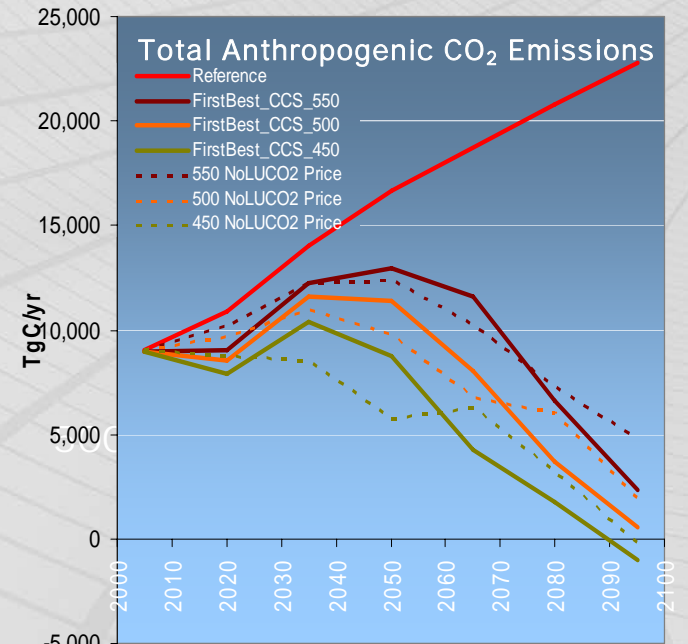
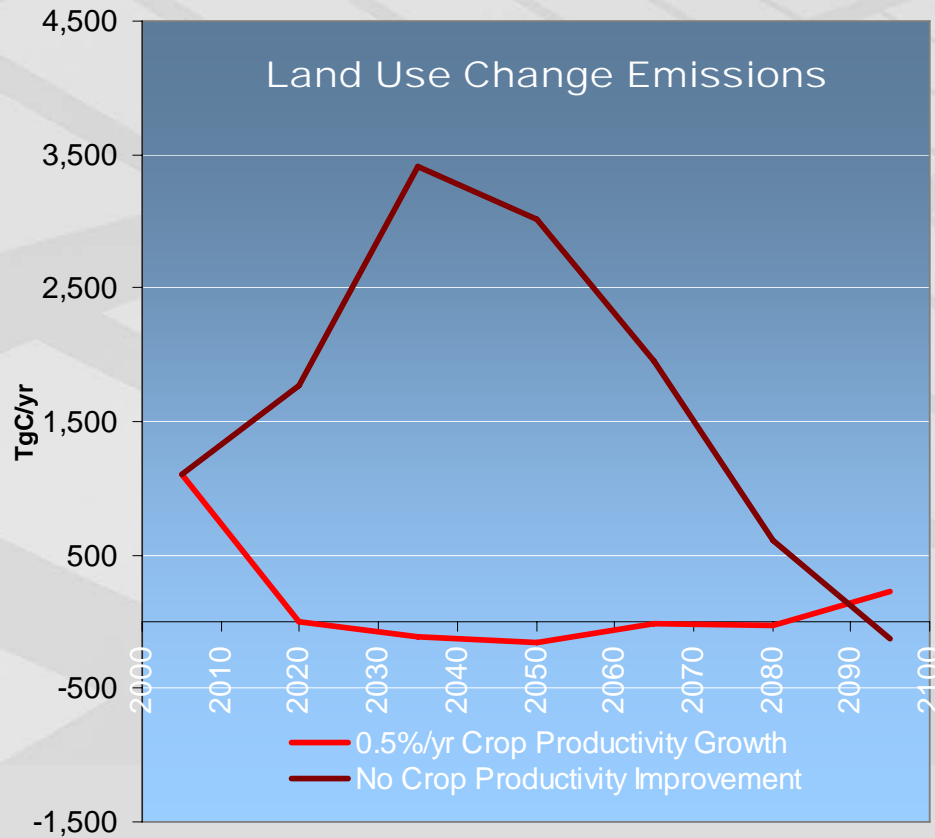
- ▶ Stabilization of greenhouse gas **concentrations** is the goal of the Framework Convention on Climate Change.
- ▶ Stabilizing CO₂ **concentrations** at any level means that **global**, CO₂ emissions must peak and then decline forever.

While it is technically possible to stabilize the concentration of greenhouse gases at virtually any level with any technology suite, the character of technology affects the cost of stabilization.

Stabilizing CO₂ concentrations means fundamental change to the global energy and land use systems



Two interesting technologies in the terrestrial system

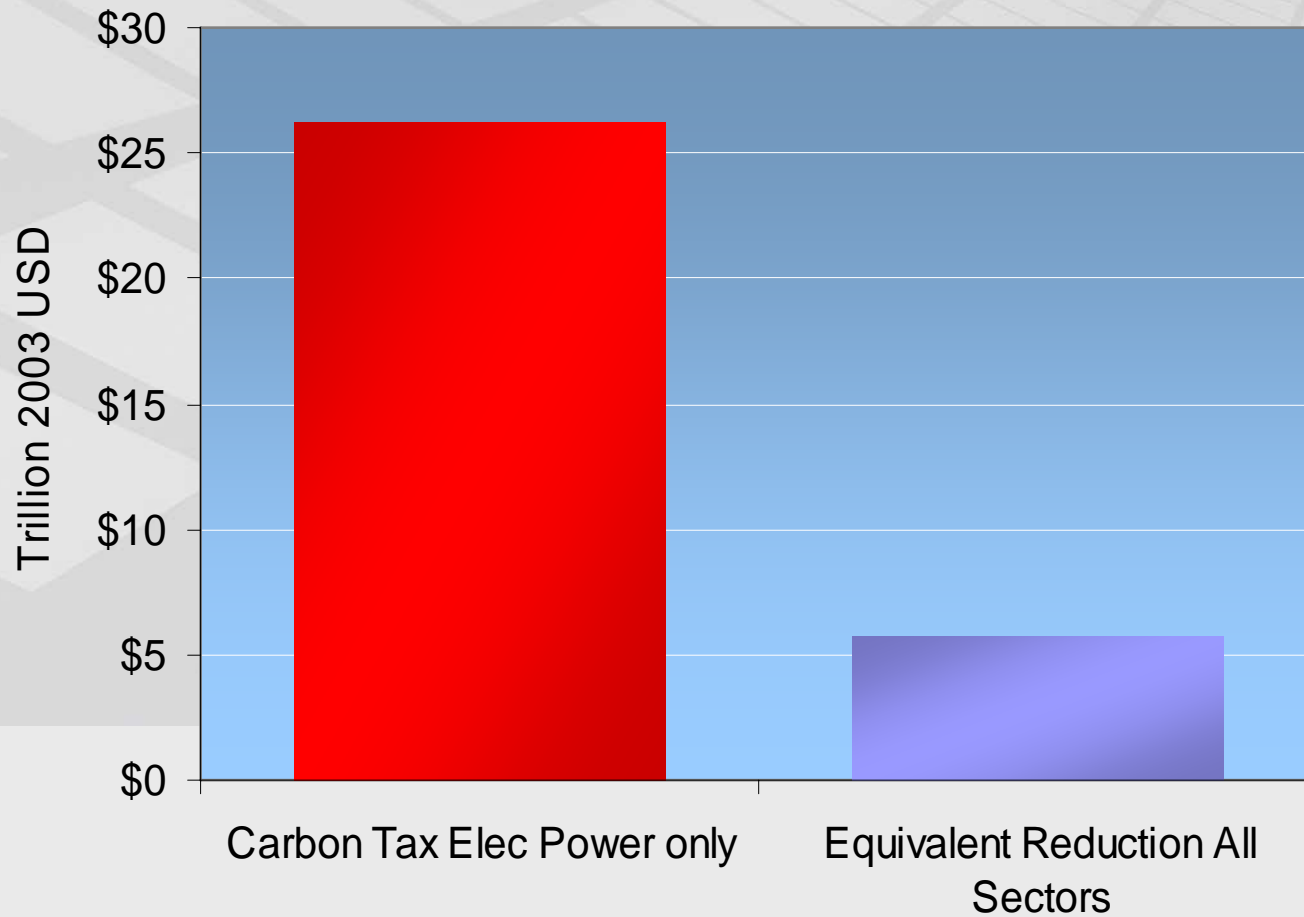


All Net Carbon Emissions Affect the Atmosphere.

- ▶ To the extent that marginal costs are similar across all emissions sources, costs will be minimized.
- ▶ To the extent that large marginal cost differences are created, then the total cost of carbon emissions mitigation will rise, and potentially by large amounts.
- ▶ Three Examples
 - *Electrification*
 - *Land use*
 - *Participation*

Electrification

If only electric power generators see carbon prices, then the cost of reducing a tonne of carbon emissions rises by a factor of FIVE.



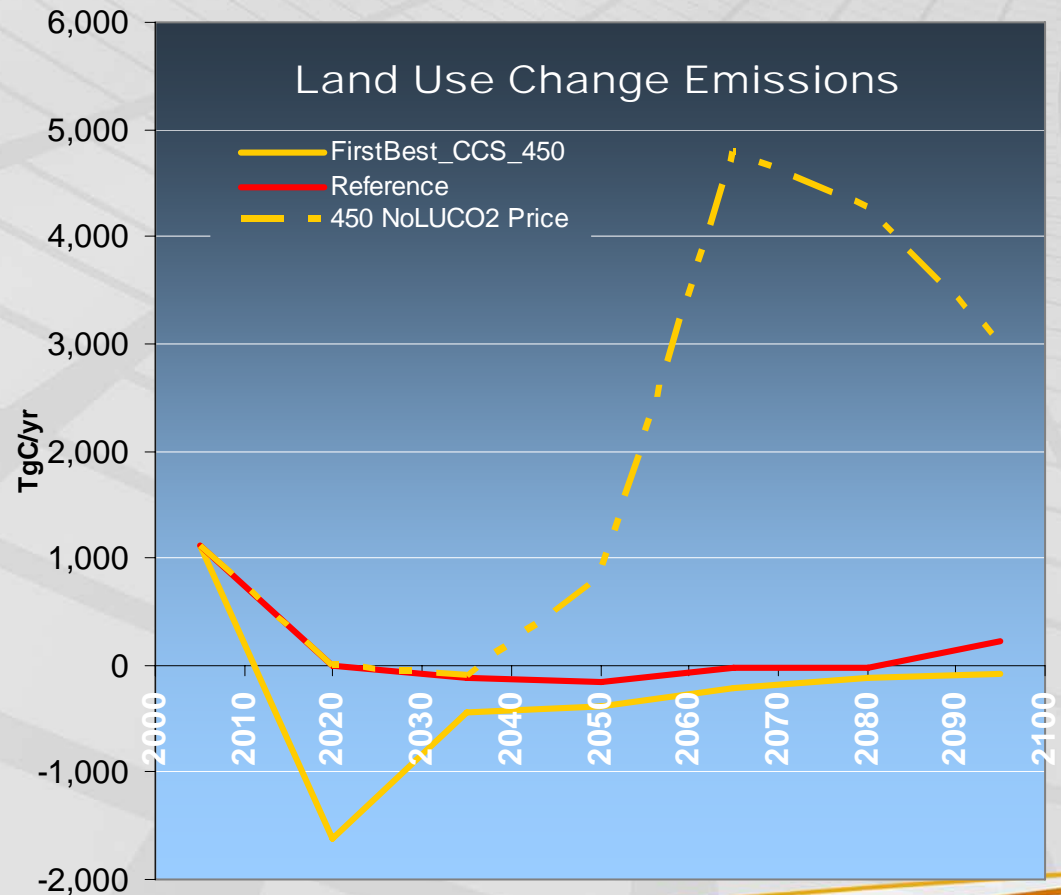
C:\aaafiles\papers & presentations\2005 morita Special Issue--Electrification paper\EPRI_Electricity_Sector_Targeted_Tax2

Land Use and Terrestrial Carbon

- ▶ Land use emissions reduction by valuing terrestrial carbon (cumulative 2005 to 2095)

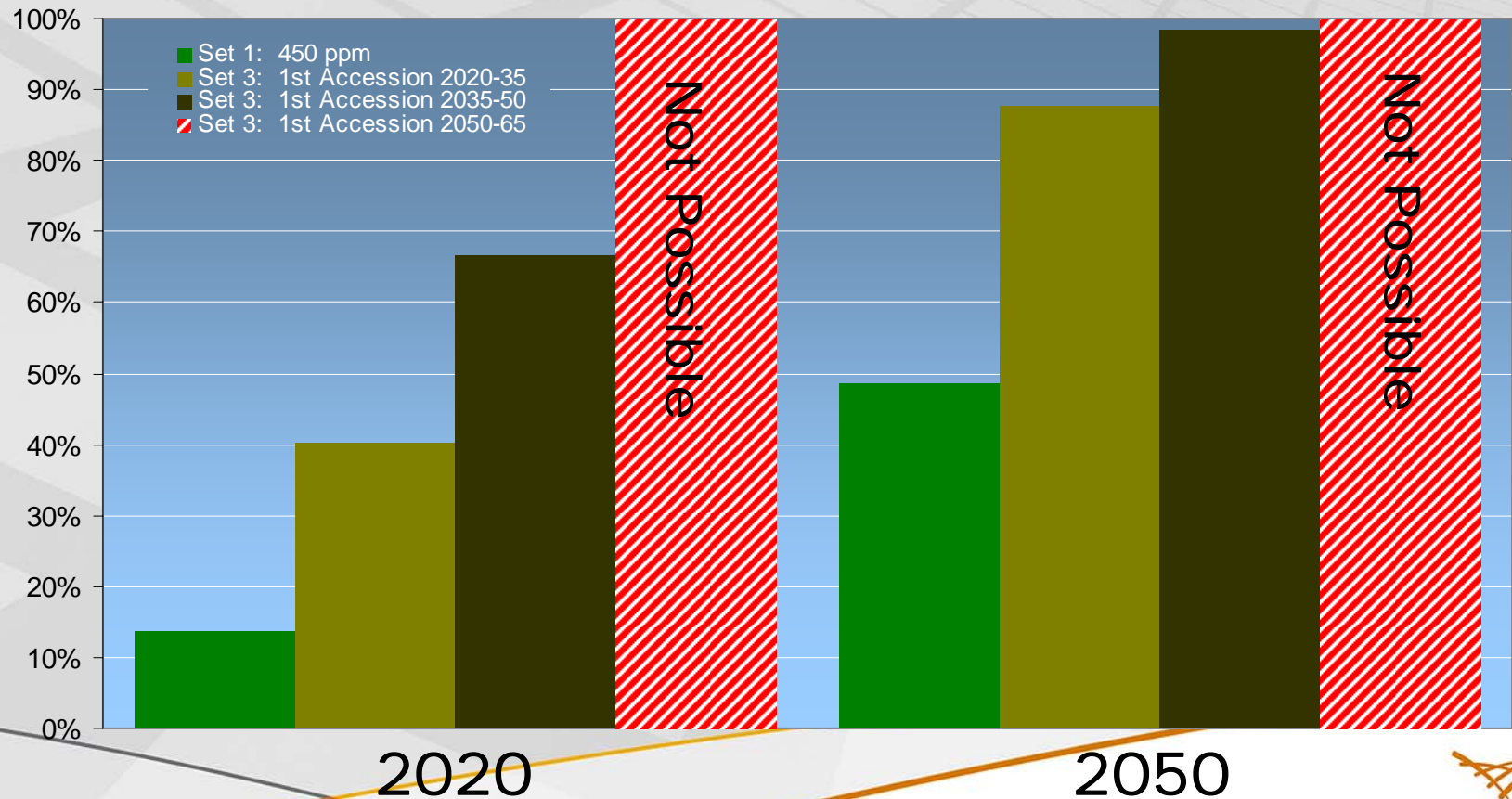
- 550 ppm 125 PgC
- 500 ppm 170 PgC
- 450 ppm 210 PgC

- ▶ Costs are halved if terrestrial carbon is valued for a 450 ppm CO₂ 2095 limit



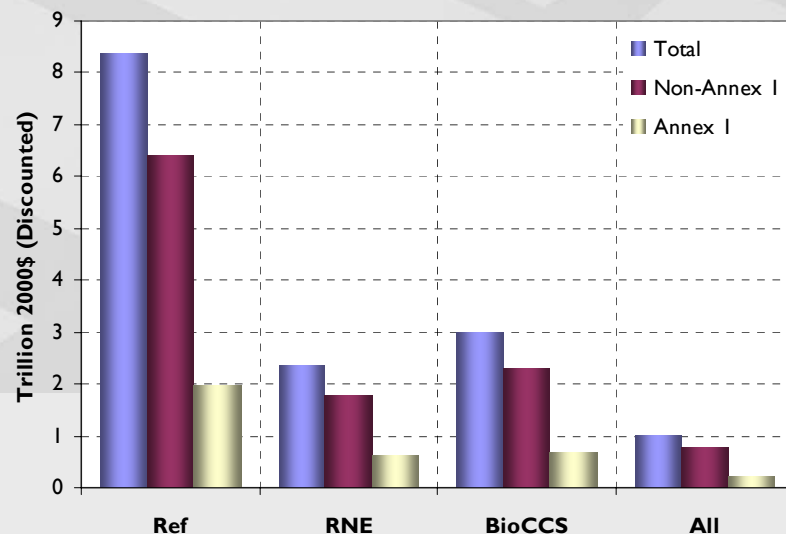
International Participation in Emissions Mitigation

Year 2020 Annex I emissions mitigation, relative to 2005, for different accession assumptions: 450 ppm

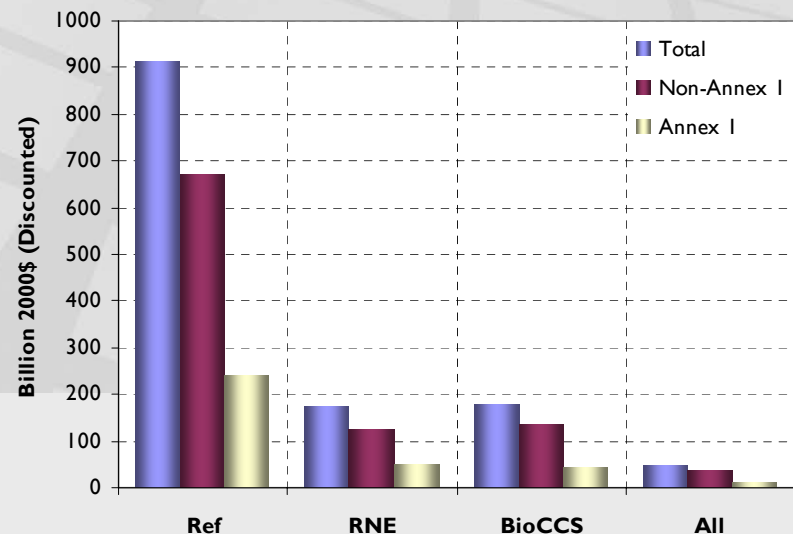


Four scenarios lead to the same place, but they are not equal.

- ▶ CO₂ concentrations were limited with all four suites.
- ▶ All four suites employed a portfolio of technologies to achieve stabilization—there is still no “silver bullet”.
- ▶ The better the technology, the lower the cost.



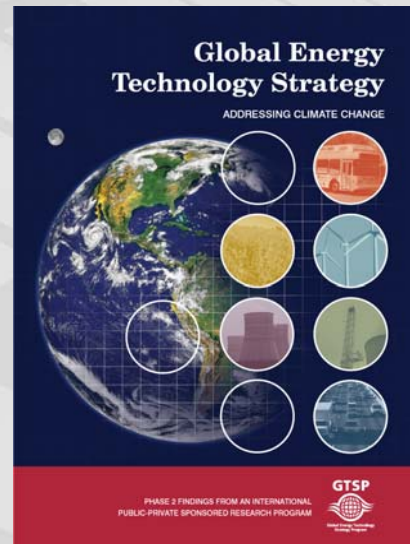
Total Discounted Cost of Mitigation,
2005 through 2095



Mitigation Cost in 2050

The GTSP Report

Copies of the Report are Available upon request



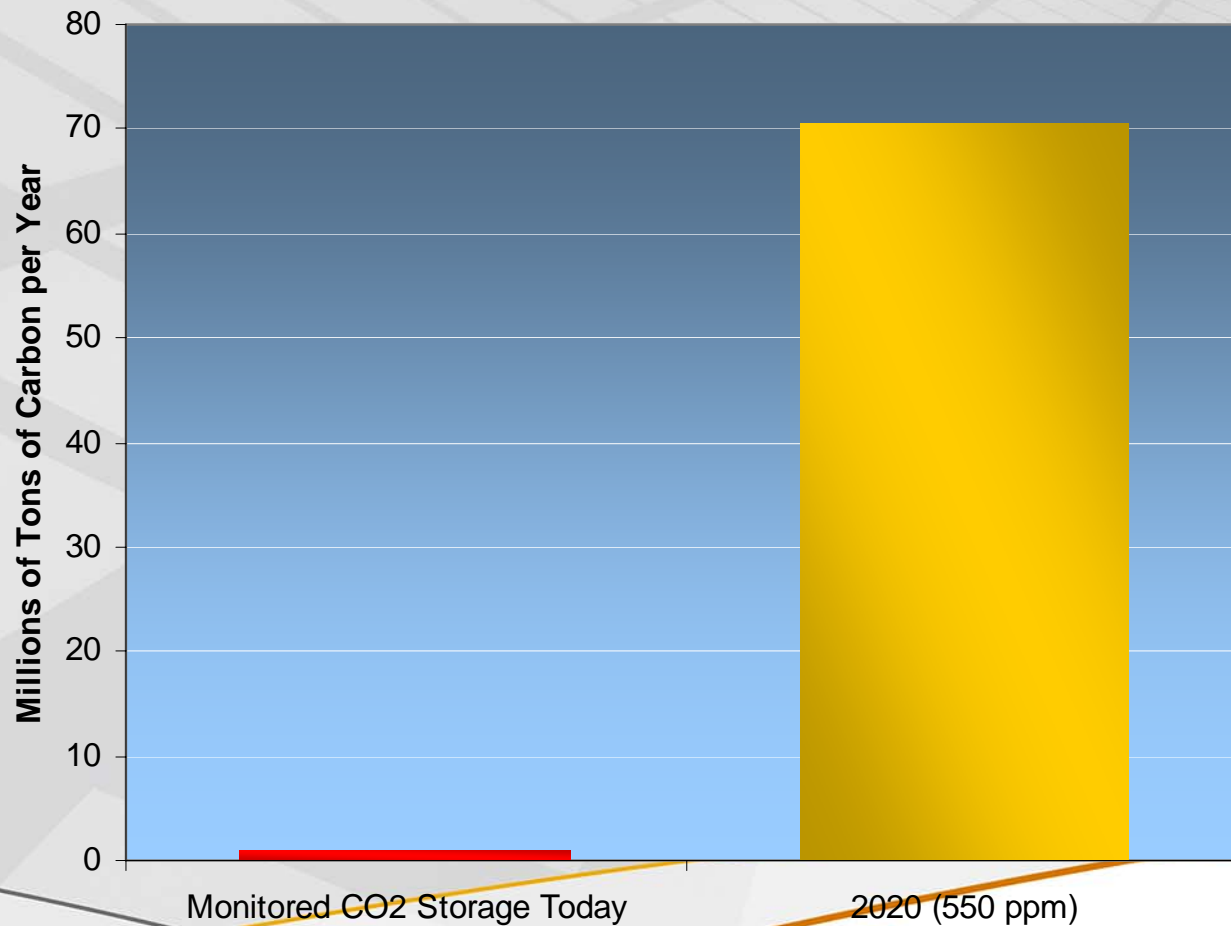
And on the Web

<http://www.pnl.gov/gtsp>

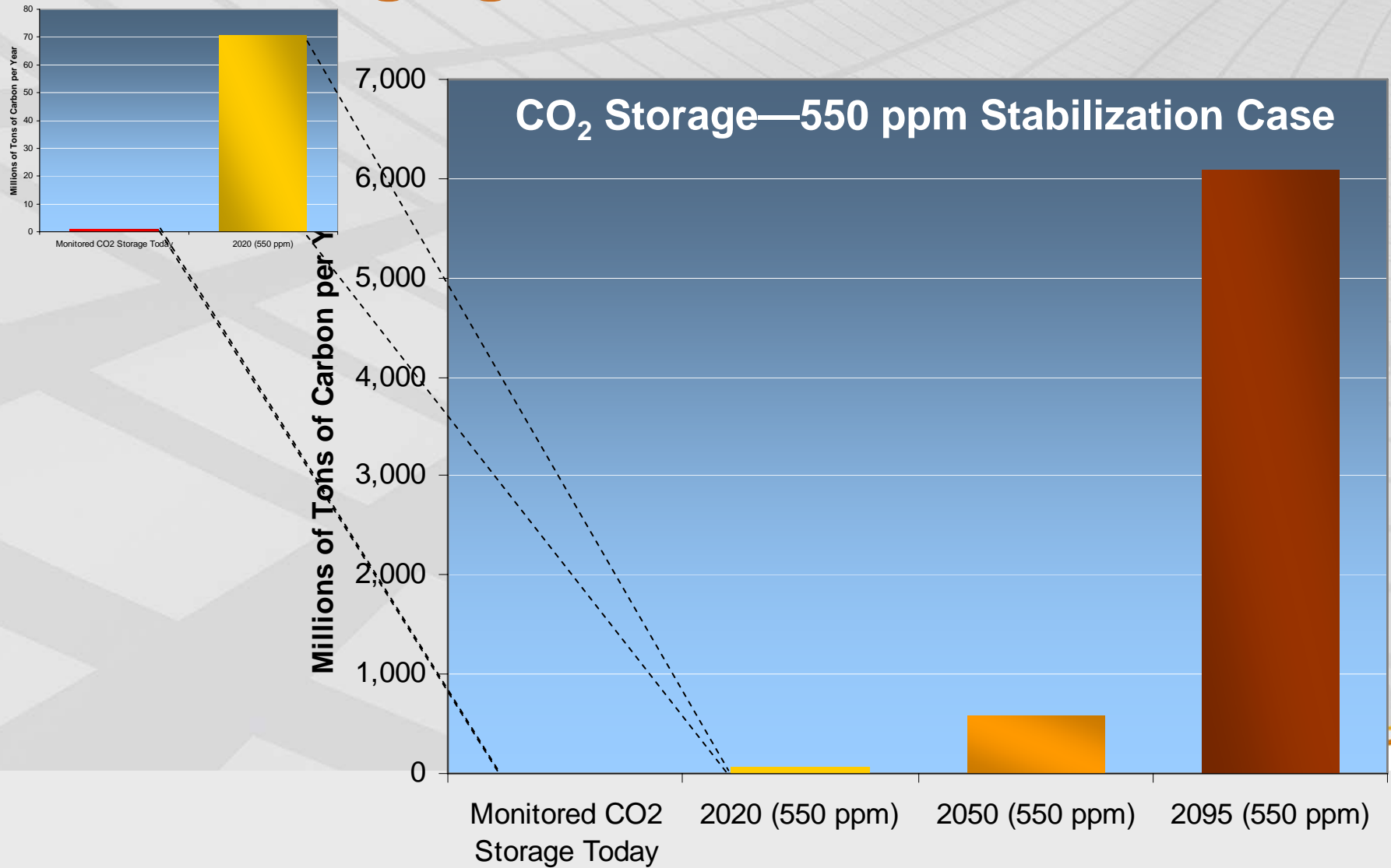
BACKUP SLIDES

6. The Challenge of Scale is Impressive— near term

CO₂ Storage—550 ppm Stabilization Case



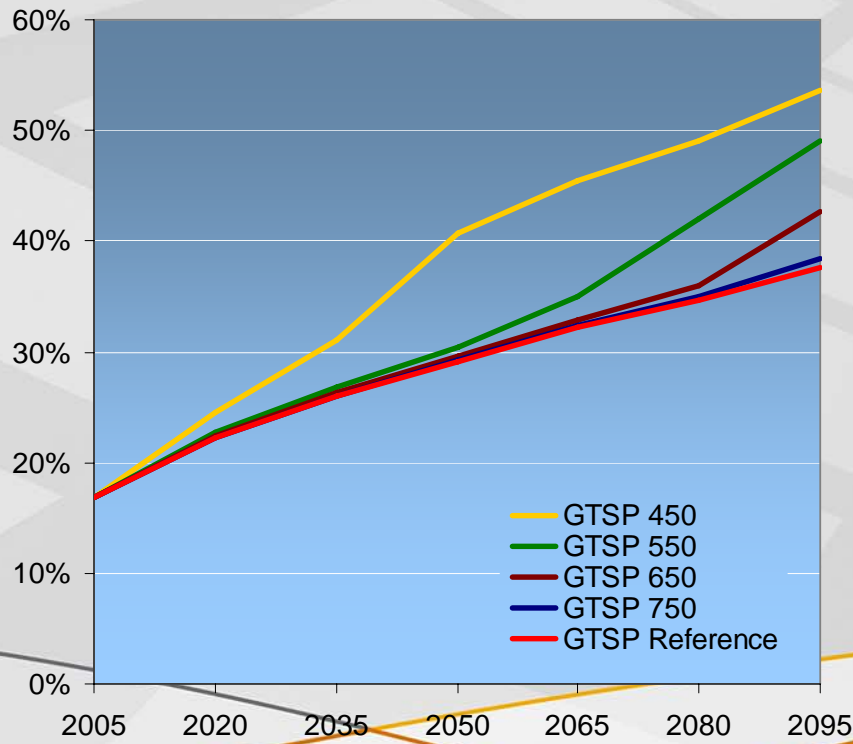
In the mid- and long-term the challenge grows



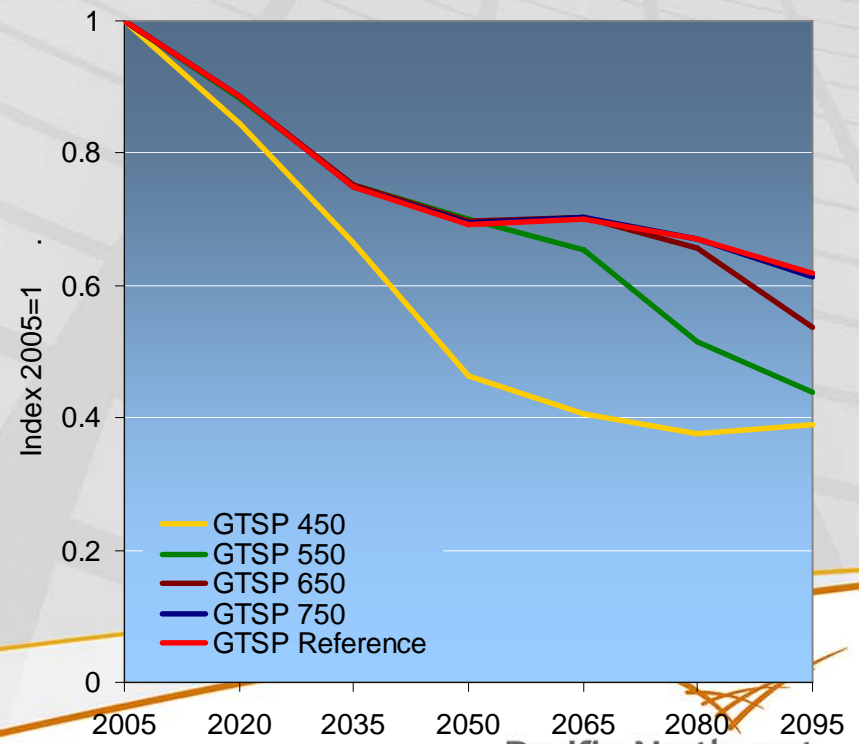
Electrification

- ▶ If all fossil fuel carbon is priced equally the price of electricity FALLS relative to its competitors in end-use markets.
- ▶ As a consequence the world electrifies.

Electricity as a Percentage of Total Final Energy



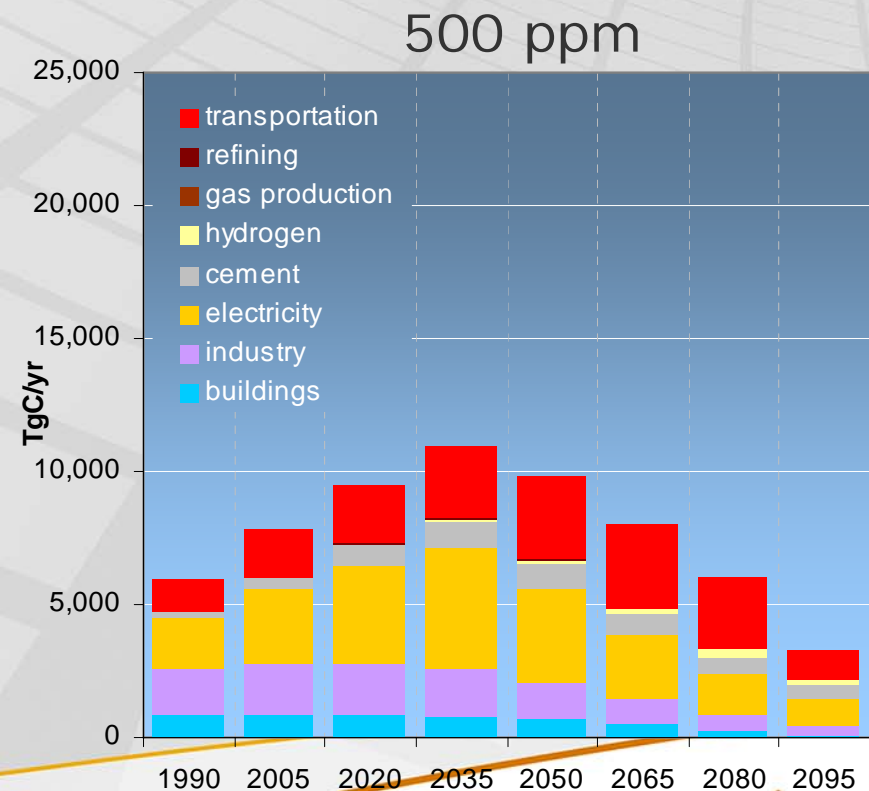
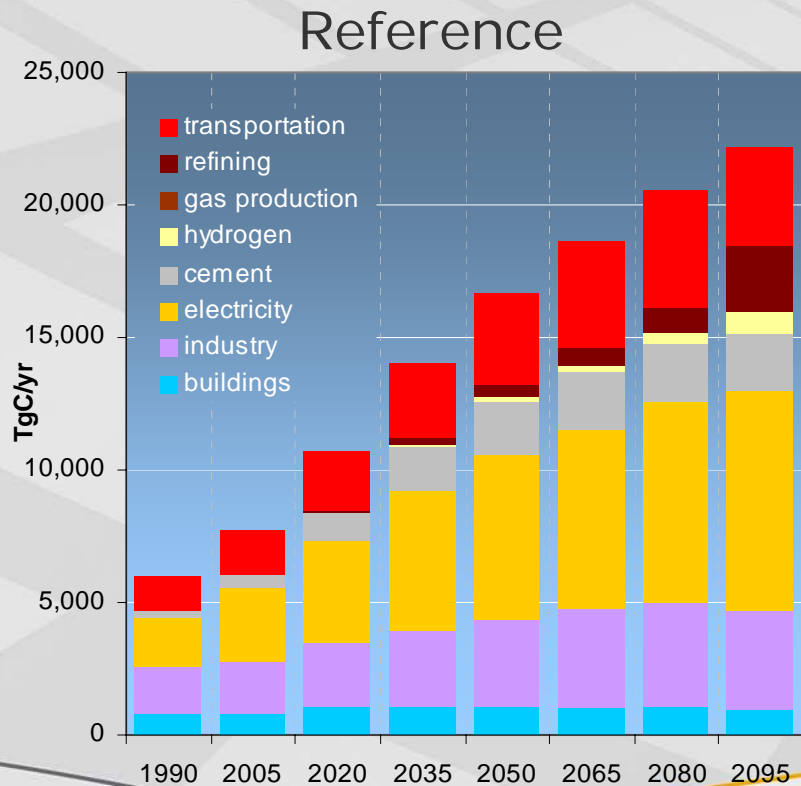
Average Electricity Price Relative to Oil Price



Electrification Over Time

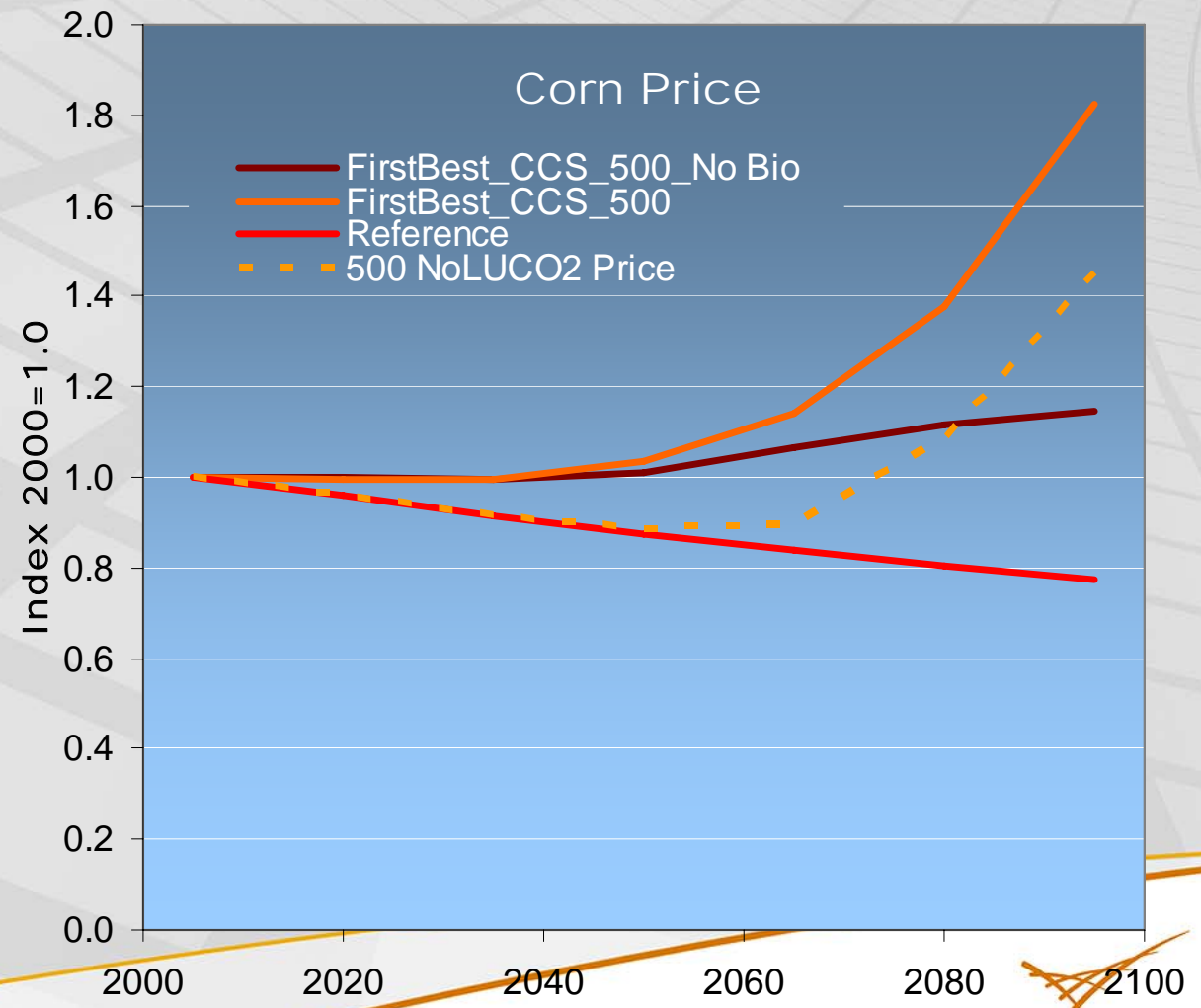
Stabilization changes the sources of fossil CO₂ emissions.

- Utility emissions drop by 90 percent.
- Buildings and Industry electrify.
- Transportation emissions dominate.



Corn Price When Carbon Is Valued But Without Purpose-grown Bioenergy

▶ Significant crop price escalation occurs if carbon is valued, even in the absence of purpose grown bioenergy production.

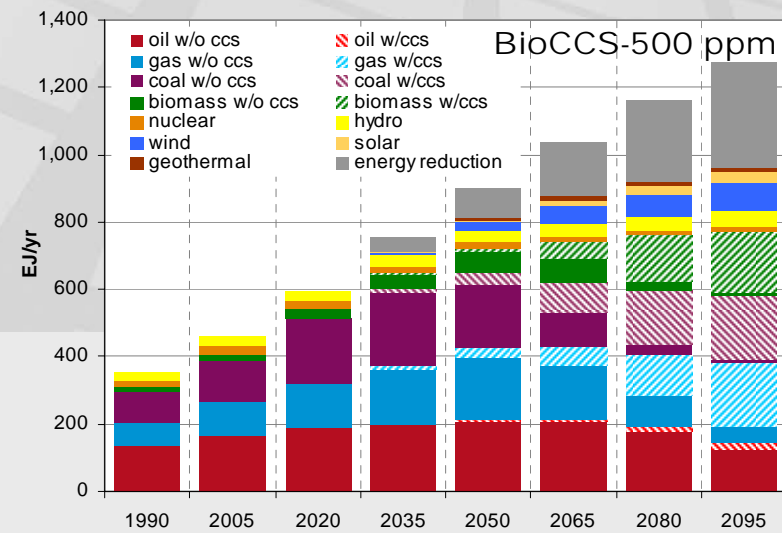
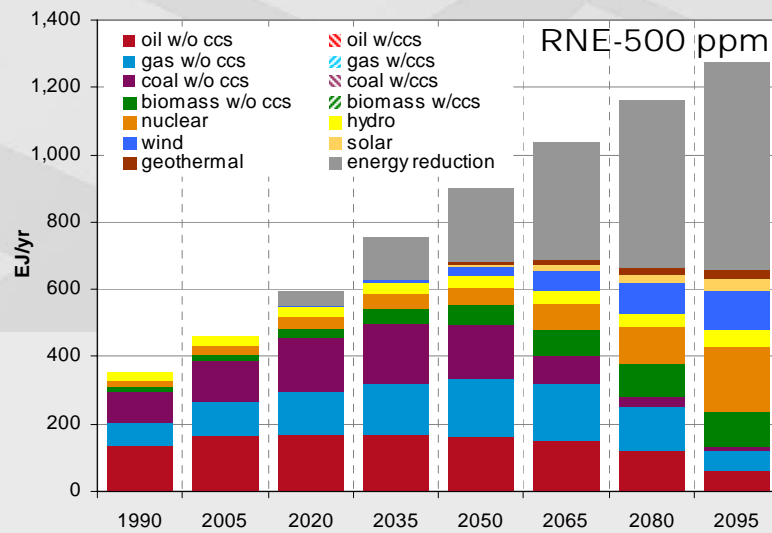
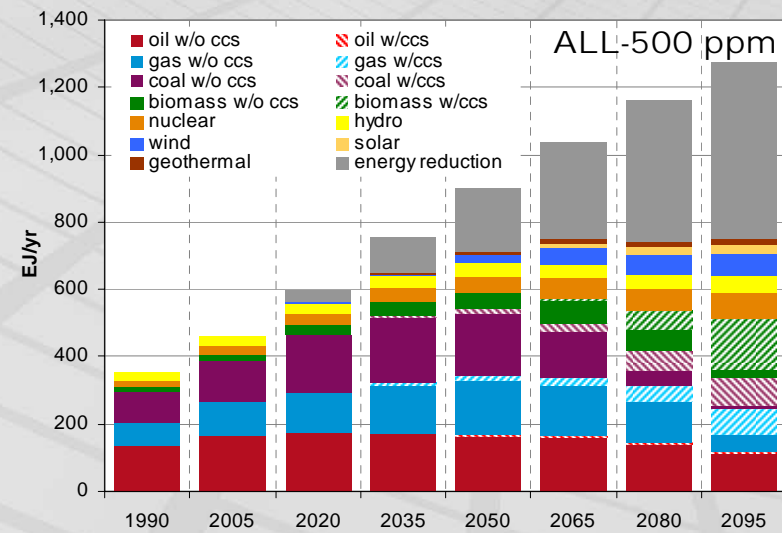
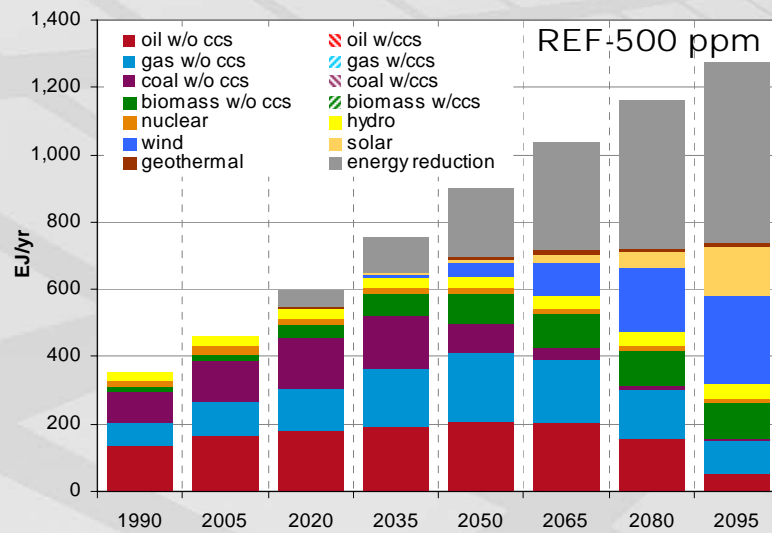


Four Alternative Technology Suites

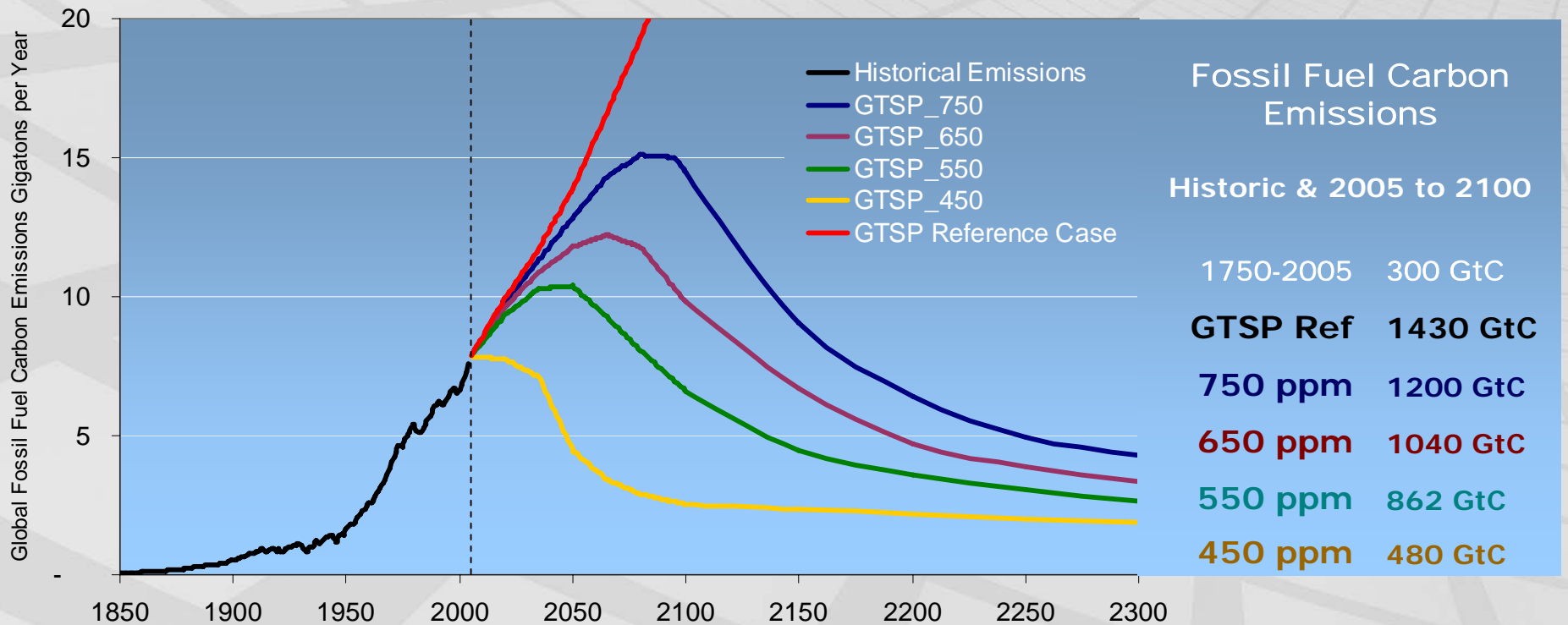
	Reference	Adv	Bio/CCS	Nuclear, Renewables, Efficiency
CCS	Low	High	High	Low
Bio	None	Base	Base	None
End Use	Low	High	Low	High
Hydrogen	Low	High	High	Low
Wind	Low	High	Low	High
Solar	Low	High	Low	High
New Nukes	No	Yes	No	Yes
Geothermal	Low	High	Low	High

And, stabilized CO₂ concentrations at 450, 500, and 550 ppm.

The Global Energy System Four Evolutionary Pathways



If Very Low Concentrations Are Desired, Then Overshoot Emissions and Concentration Trajectories May Become More Important



- ▶ We generally think of stabilization scenarios as “Rise to and Maintain” trajectories.
- ▶ This approach excludes the possibility of very low concentrations.
- ▶ Very low concentrations require overshooting the eventual concentration and subsequently declining to it.

Net Long-term Carbon Emissions for Some Steady-state Concentration

- ▶ The world would eventually return to 350 ppm after 800 PgC net emissions (300 PgC since 1750 + 500 PgC additional).
 - Cumulative emissions usually associated with 450 ppm stabilization.
- ▶ **Negative emissions mean that Very low steady-state concentrations are thinkable:**
 - How long above the very long-term value?
 - How high above the long-term value?
 - How much irreversible change?

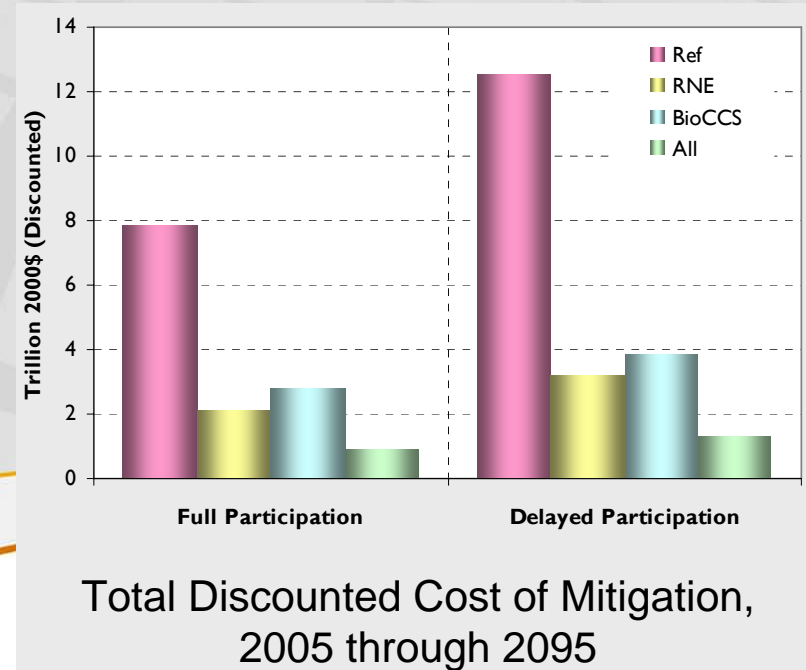
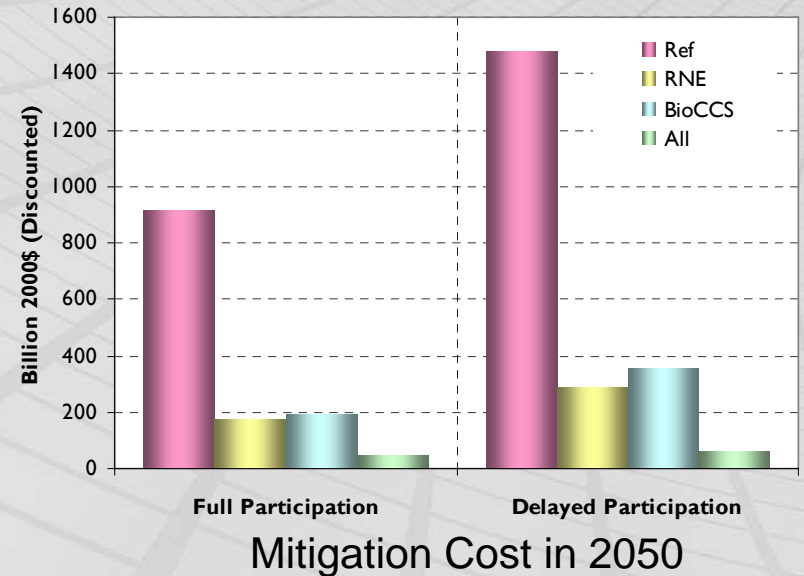
CO ₂ Concentration (ppm)	Cumulative Emissions (PgC)
275	0
300	292
325	560
350	808
375	1,039
400	1,255
425	1,459
450	1,653
500	2,010
550	2,338
600	2,641
650	2,924

The World Will Be A Second Best, or Third Best or ...

- ▶ While climate change implies large forces shaping the future global energy and land-use systems, it is not the only force.
- ▶ Minimizing the cost of meeting a climate constraint in the presence of other constraints may not be simple—e.g. bioenergy.
- ▶ In addition, other issues will overlay and interact with the energy-land-use-climate issue—e.g. energy security, local air quality, sustainability.

Technology is even more important in an imperfect world

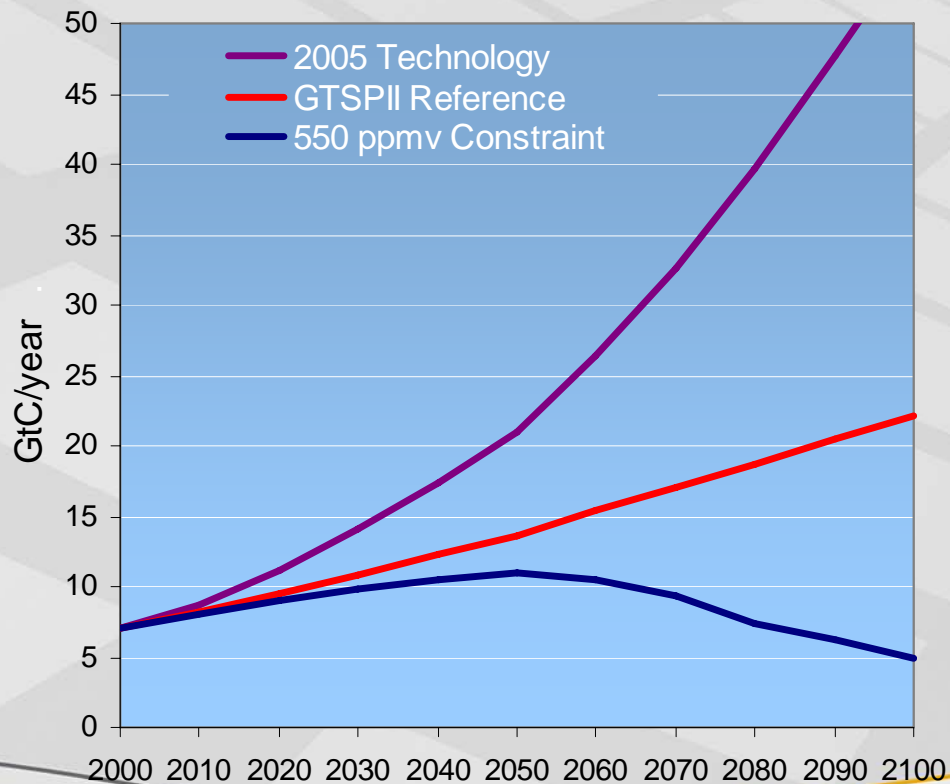
- ▶ In the real world we will almost certainly have to live with second- and third-best solutions.
- ▶ Technology improvement can be even more valuable in an imperfect world than in a perfect world.



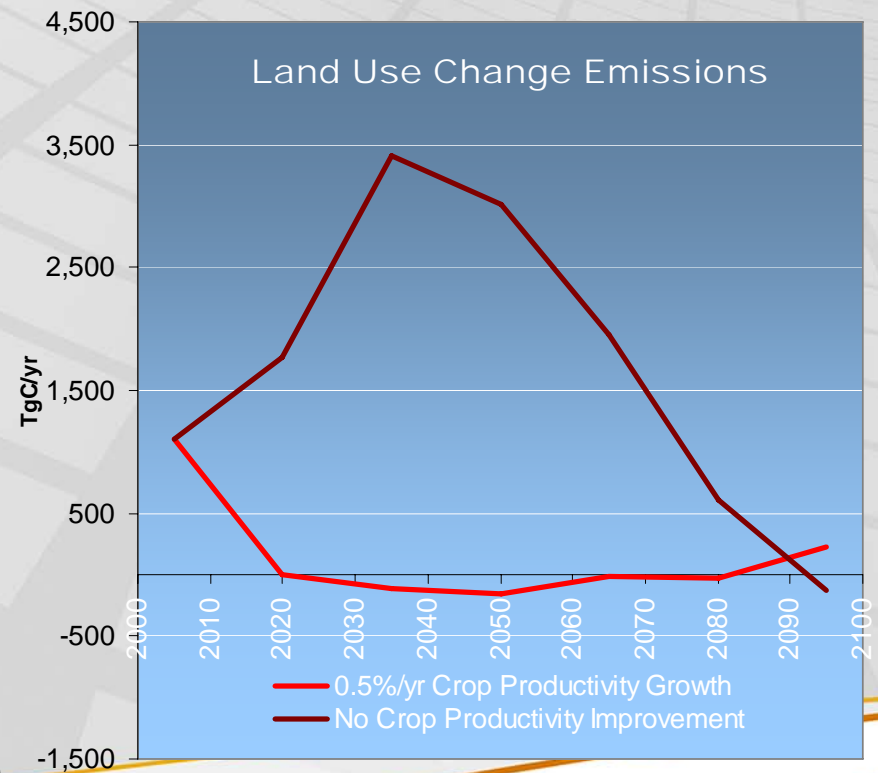
Technology is needed to address climate change in the near, mid, and long terms implying the need for a portfolio of R&D and basic science investments.

Future projections of energy use and CO₂ emissions assume significant technological progress in their no-climate-policy, business-as-usual cases

Carbon Emissions

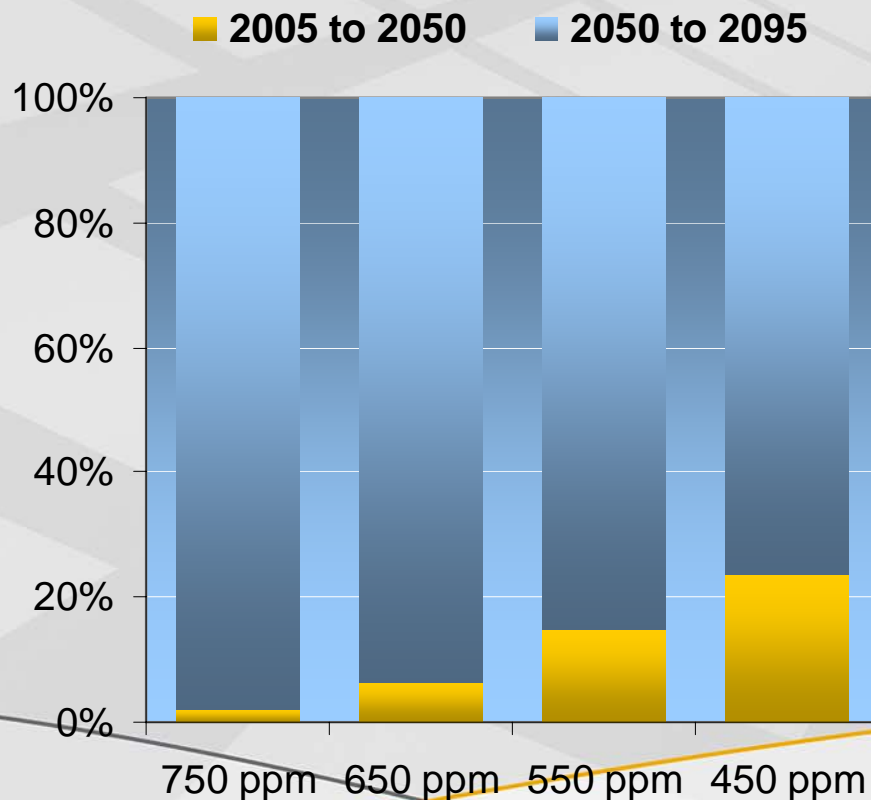


Land Use Change Emissions



The Challenge of Emissions Mitigation Accelerates Over Time

Emissions Mitigation 2005 to 2050 and 2050 to 2095



- ▶ While the mitigation supply schedule for MIT and MiniCAM were similar up to the year 2050 in the CCSP SAP 2.1a, near-term carbon prices were much higher in the MIT scenarios. This is in part due to differences in technology availability in the post-2050 period.
- ▶ Investments in basic scientific research in the first half of the 21st century can be transformed into energy technologies that can become a major part of the global energy system in the second half of the century.